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(54) **ACTUATOR OF LINK MECHANISM FOR INTERNAL COMBUSTION ENGINE AND ACTUATOR FOR VARIABLE COMPRESSION RATIO MECHANISM**

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F02D 15/02 (2006.01)

(52) **U.S. Cl.**
CPC ***F02D 15/02*** (2013.01); ***F02B 75/045*** (2013.01); ***F02B 75/048*** (2013.01)

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USPC .... 123/48 R, 48 B, 78 R, 78 BA
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2002/0043228 A1* 4/2002 Moteki .... F02B 75/045 123/78 E
2013/0327302 A1* 12/2013 Hiyoshi .... F02B 75/04 123/48 R
2015/0176507 A1* 6/2015 Tanaka .... F02F 7/0068 123/48 R

FOREIGN PATENT DOCUMENTS

JP 2011-169152 A 9/2011

OTHER PUBLICATIONS

U.S. Appl. No. 14/613,035, filed Feb. 3, 2015, Onigata et al.

* cited by examiner

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(57) **ABSTRACT**

An actuator of a variable compression ratio mechanism which includes: a control link; a control shaft; a housing; a wave gear speed reduction device arranged to transmit the reduced rotation speed to the control shaft; a first bearing portion which is provided between the control shaft and a wave generation device of the wave gear speed reduction device, and which rotatably supports a first axial end portion of the wave generation device; and a second bearing portion which is provided between the housing and the wave generation device, and which rotatably supports an second axial end portion of the wave generation device, at least one of the first bearing portion and the second bearing portion being disposed inside an axial width of an outer circumference portion of the wave generation device.

16 Claims, 7 Drawing Sheets

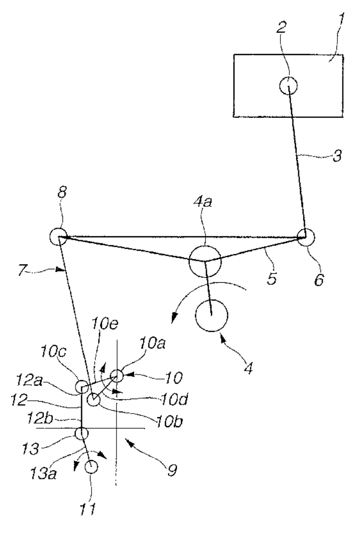


FIG.1

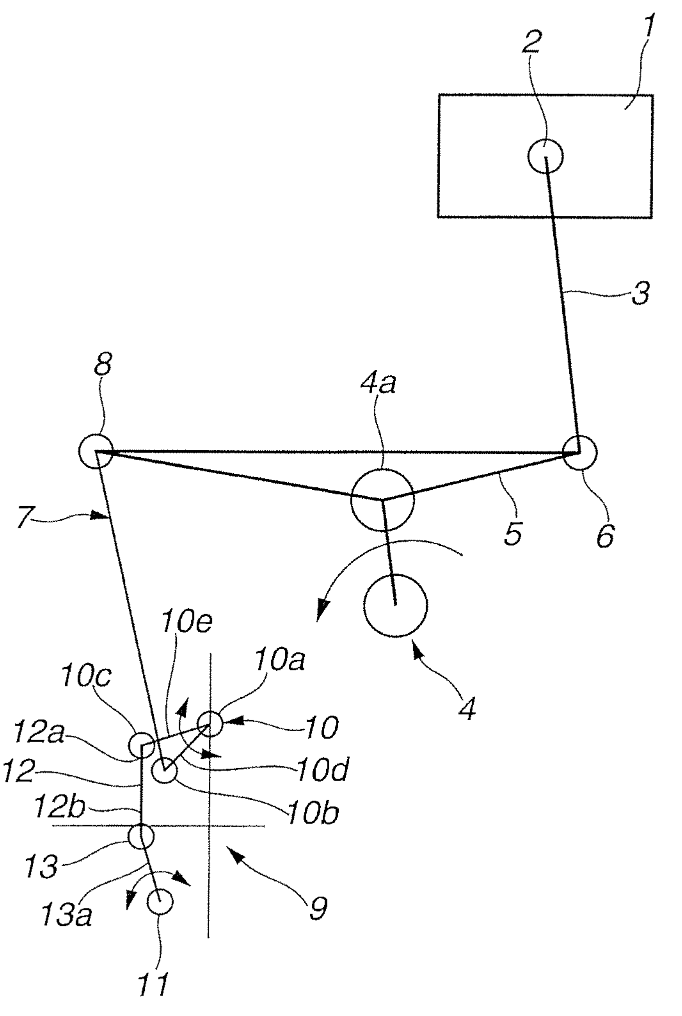
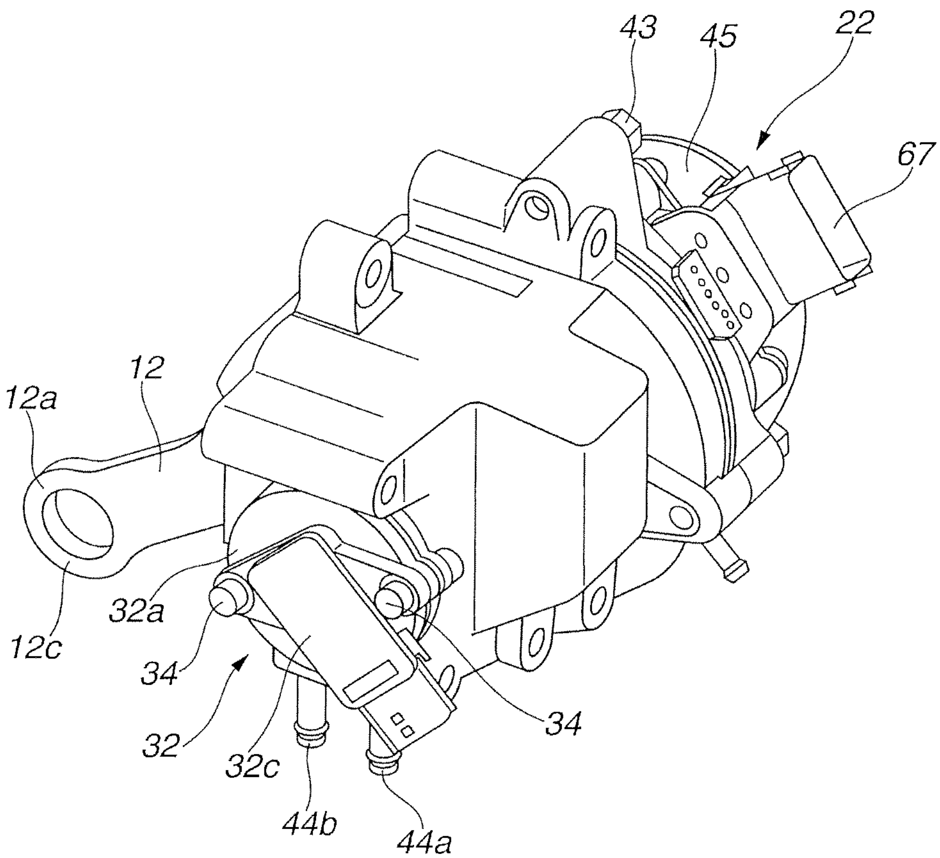
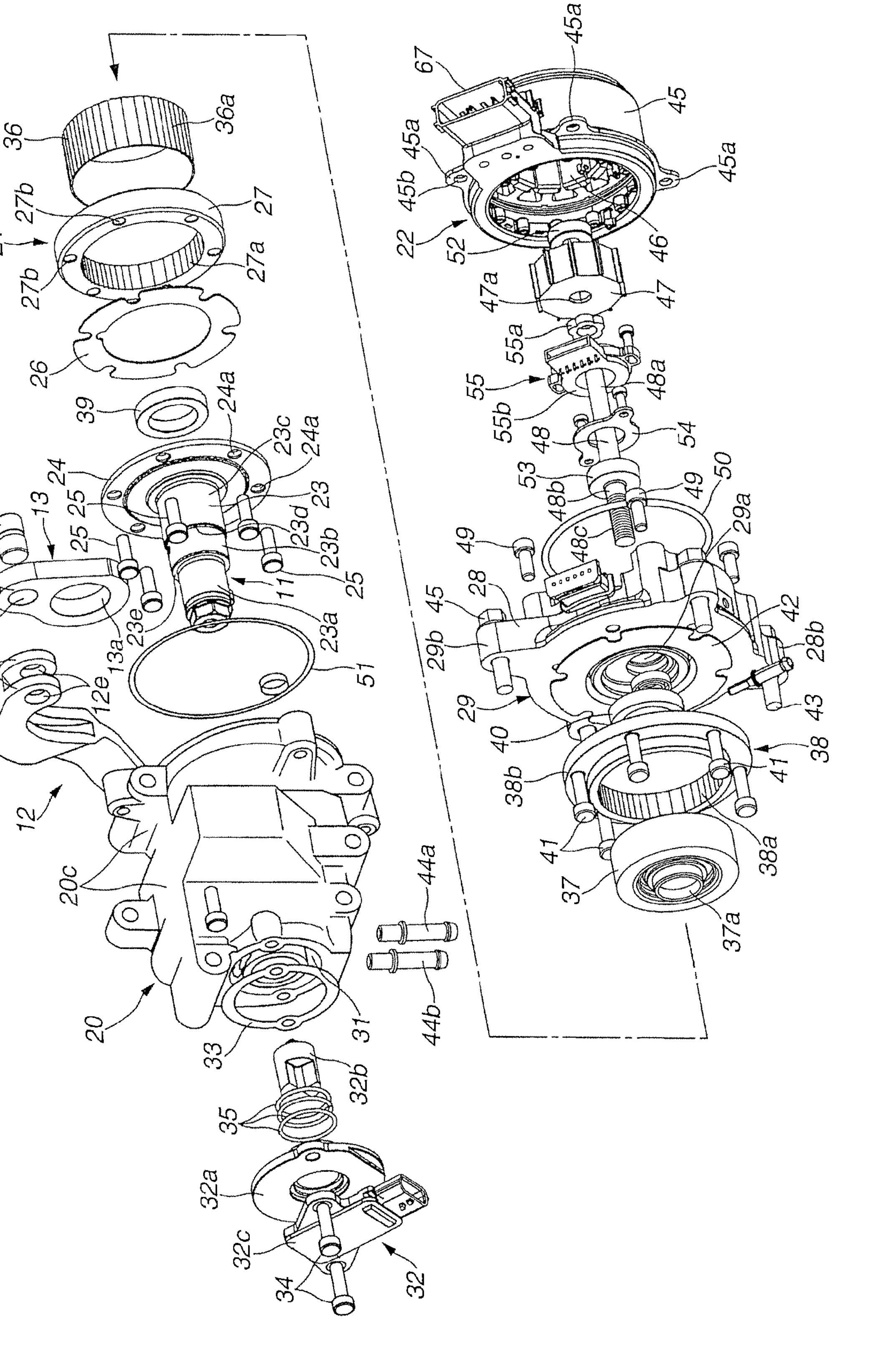


FIG.2

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48c
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29a
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37a

FIG.3

FIG.4

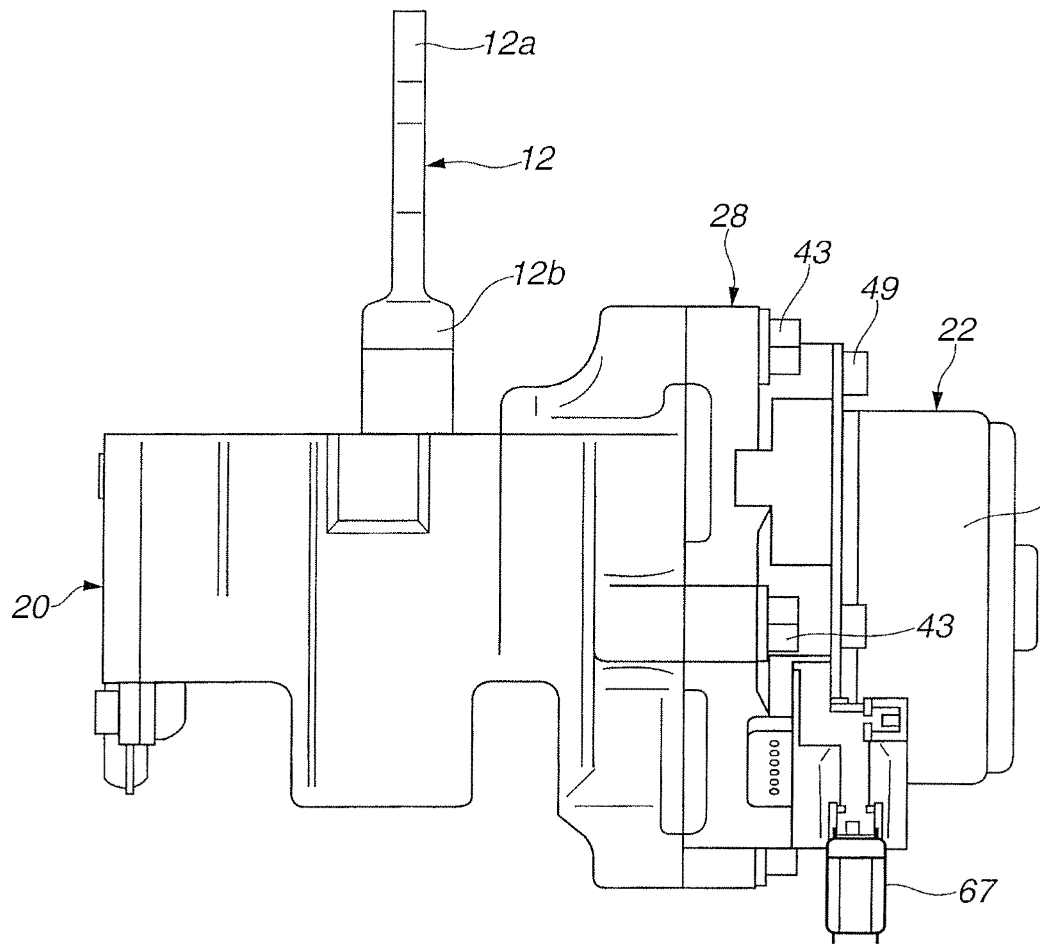


FIG.5

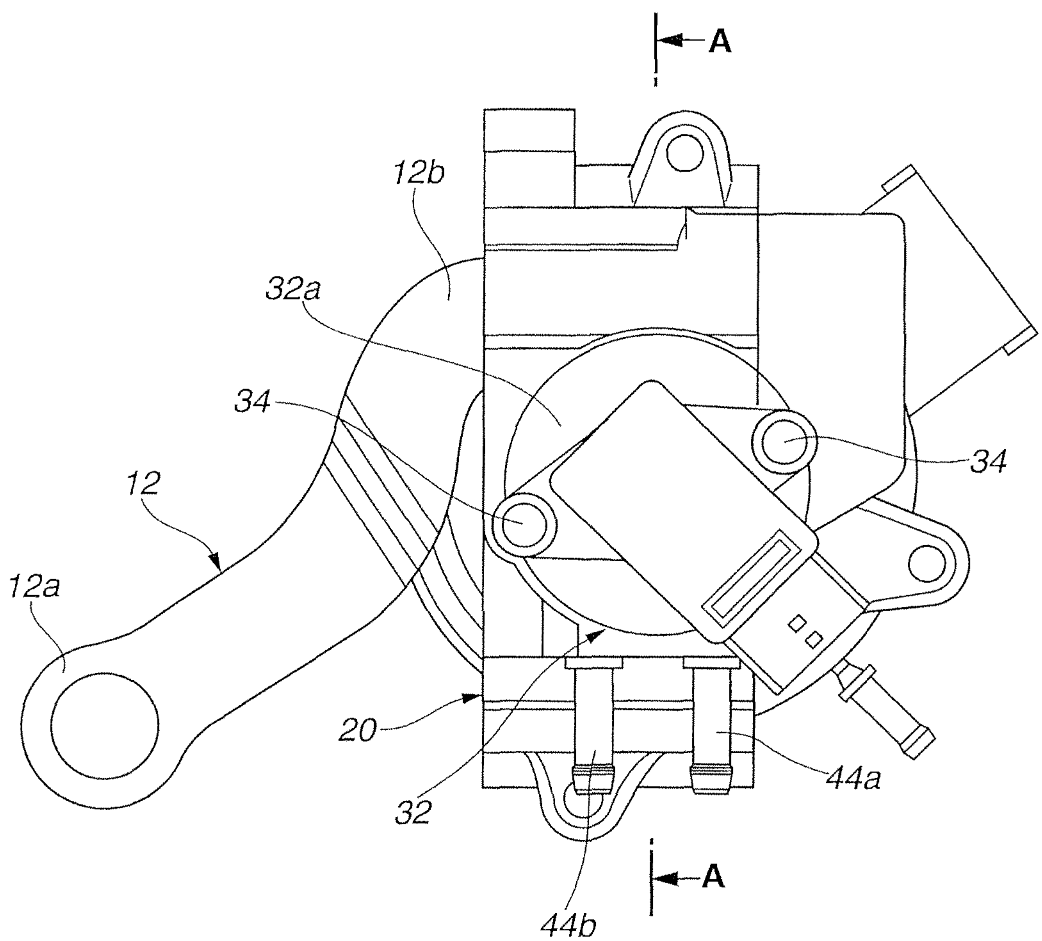
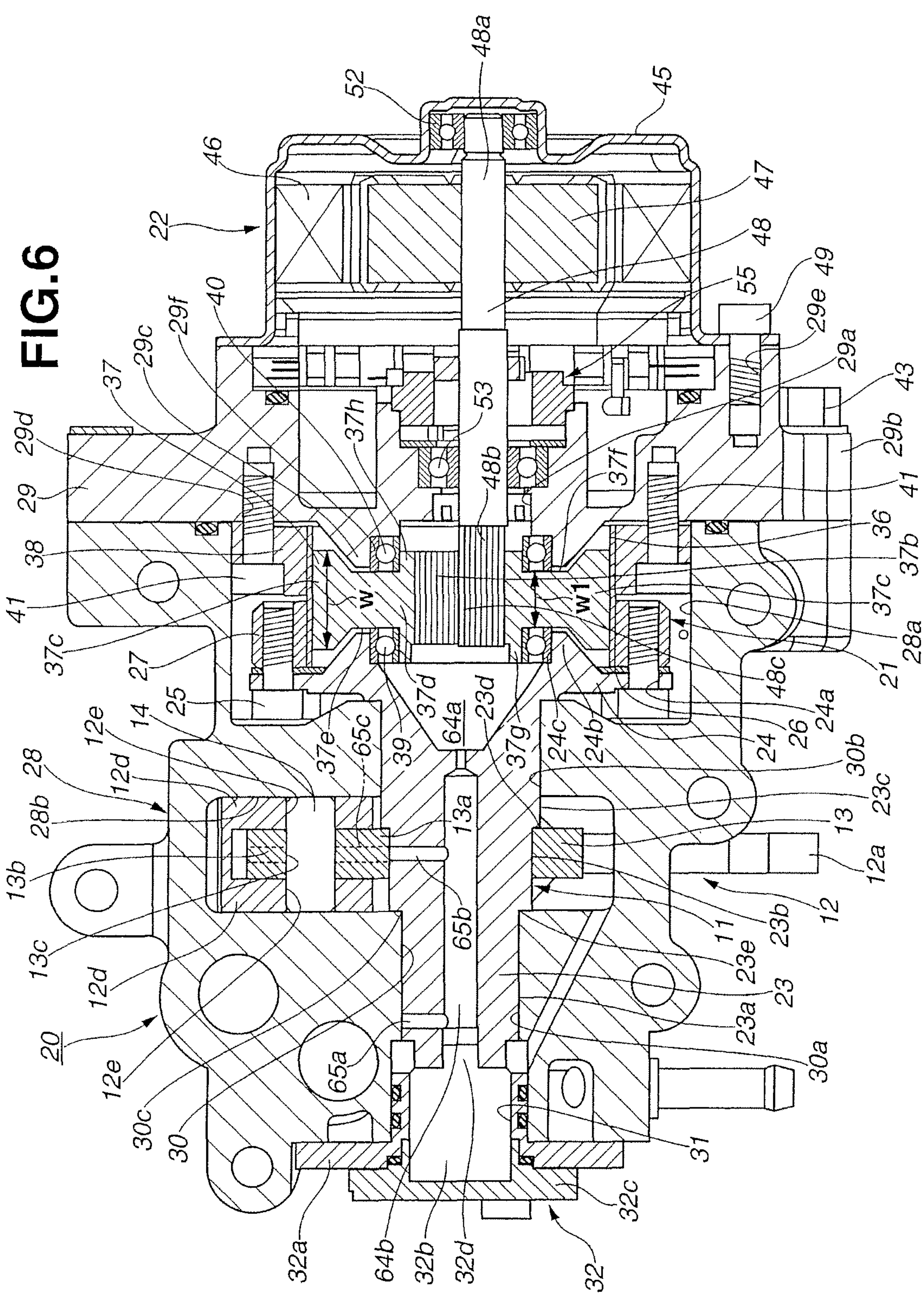


FIG.6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24b
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12a
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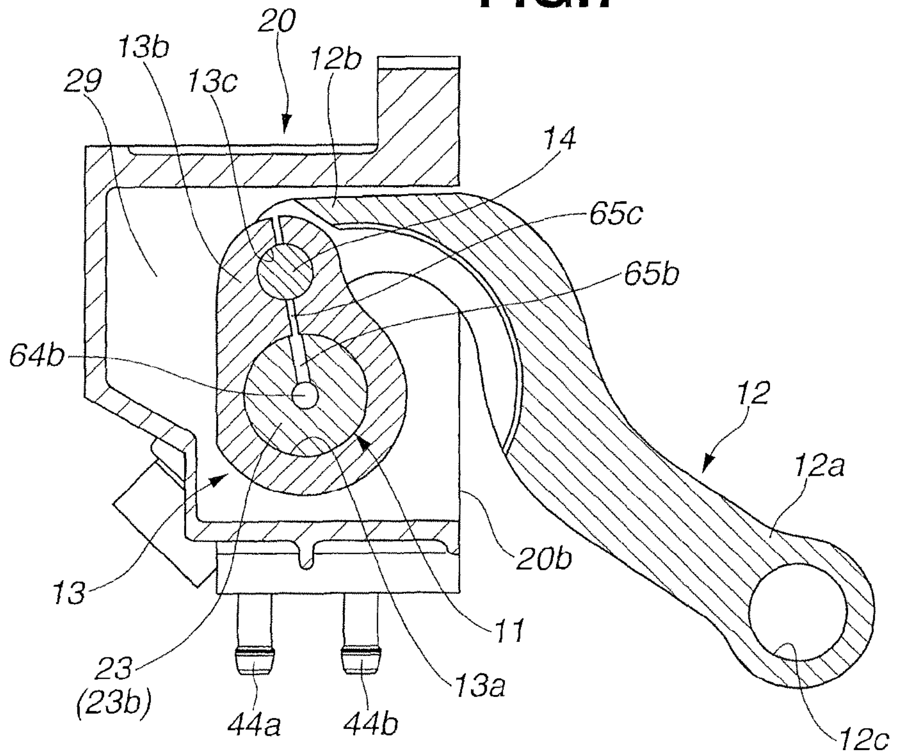
W1

FIG.7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13c
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(23b)
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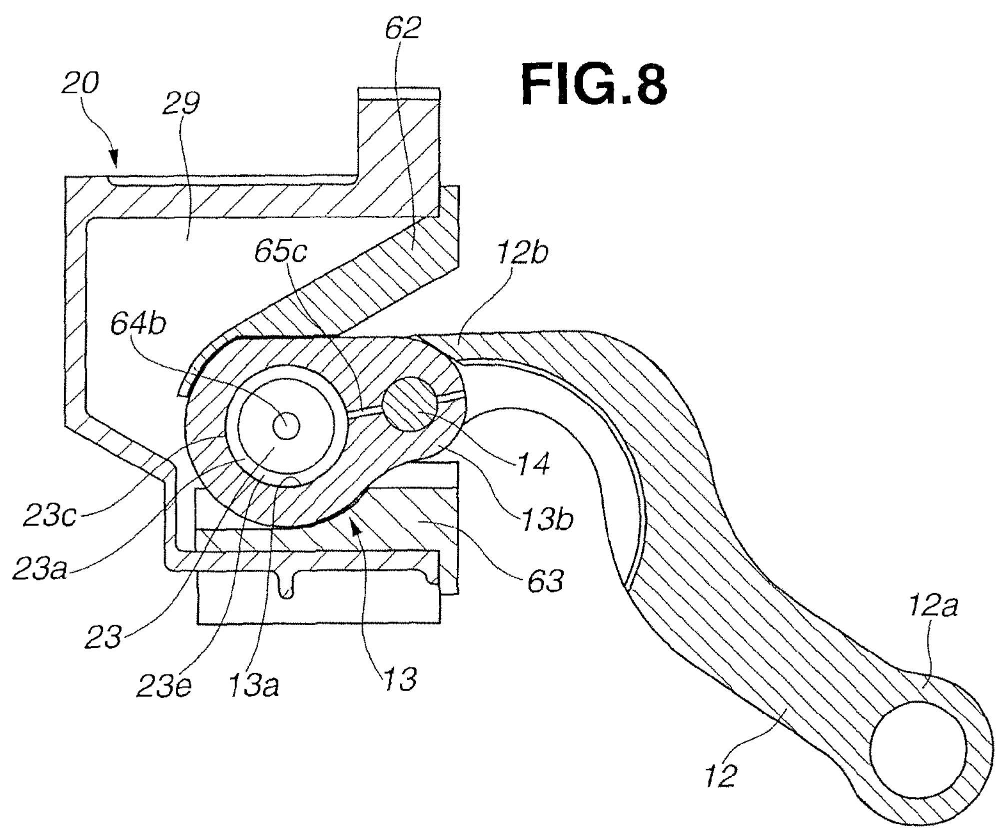
44b
12c

FIG.8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12a
12

ACTUATOR OF LINK MECHANISM FOR INTERNAL COMBUSTION ENGINE AND ACTUATOR FOR VARIABLE COMPRESSION RATIO MECHANISM

BACKGROUND OF THE INVENTION

This invention relates to a link mechanism for an internal combustion engine which is used for a variable valve actuating apparatus that is arranged to vary operation characteristics of engine valve of an intake valve and/or an exhaust valve of an internal combustion engine, and an actuator for a variable compression ratio mechanism which is arranged to vary an actual mechanical compression ratio of the internal combustion engine.

A Japanese Patent Application Publication No. 2011-169152 discloses a conventional variable compression ratio mechanism which uses multi-link piston-crank mechanism, and which is arranged to vary a mechanical compression ratio.

That is, a piston and a crank shaft are connected through an upper link and a lower link. A posture of the lower link is controlled by an actuator including a driving motor and a speed reduction device. With this, a piston stroke characteristic of the piston is varied to control the engine compression ratio.

SUMMARY OF THE INVENTION

However, in the above-described actuator of the conventional compression ratio mechanism, the control shaft is rotatably supported within the housing. The speed reduction device is provided at one end portion of the housing. The drive motor is coaxially disposed at an end portion of the speed reduction device. Accordingly, the entire axial length of the actuator becomes long. Consequently, a layout within the lower portion of the engine main body is restricted. The disposition may be difficult.

It is, therefore, an object of the present invention to provide a link mechanism and an actuator of a variable compression ratio mechanism which are devised to solve the above-described problems, to decrease the entire size by decreasing an axial length of the actuator.

According to one aspect of the present invention, an actuator of a variable compression ratio mechanism which is arranged to vary at least one of a top dead center position and a bottom dead center position of a piston of an internal combustion engine, and thereby to vary a mechanical compression ratio, the actuator comprises: a control link including a first end portion connected to the variable compression ratio mechanism, and a second end portion, and arranged to vary a position characteristic of the piston; a control shaft which is connected in an eccentric state through an arm link to the second end portion of the control link; a housing which includes a support hole formed within the housing, and which rotatably supports the control shaft; a wave gear speed reduction device which is arranged to reduce a rotation speed of a drive motor, and to transmit the reduced rotation speed to the control shaft; a first bearing portion which is provided between the control shaft and a wave generation device of the wave gear speed reduction device, and which rotatably supports a first axial end portion of the wave generation device; and a second bearing portion which is provided between the housing and the wave generation device, and which rotatably supports an second axial end portion of the wave generation device, at least one of the first bearing portion and the second bearing portion being dis-

posed inside an axial width of an outer circumference portion of the wave generation device.

According to another aspect of the invention, An actuator of a variable compression ratio mechanism which is arranged to vary at least one of a top dead center position and a bottom dead center position of a piston of an internal combustion engine, and thereby to vary a mechanical compression ratio, the actuator comprises: a control shaft arranged to be drivingly rotated by a drive motor; a control link which includes a first end portion connected to the variable compression ratio mechanism, and a second end portion linked with the control shaft, and which is arranged to vary a position characteristic by a rotation of the control shaft; a housing which includes a support hole formed within the housing, and which rotatably supports the control shaft; a wave gear speed reduction device which is arranged to reduce a rotation speed of a drive motor, and to transmit the reduced rotation speed to the control shaft; a first bearing portion including an outer wheel which is fixed on an inner circumference portion of the control shaft, and an inner wheel which is fixed to a first axial end portion of an inner circumference portion of the wave generation device; and a second bearing portion including an outer wheel fixed to the housing, and an inner wheel fixed to a second axial end portion of the inner circumference portion of the wave generation device, at least one of the first axial end portion and the second axial end portion of the inner circumference portion of the wave generation device including a recessed portion, and a part of at least one of the first bearing portion and the second bearing portion being received within the recessed portion.

According to still another aspect of the invention, an actuator used for driving a link mechanism of an internal combustion engine, the actuator comprises: a control link including a first end portion connected to the link mechanism; a control shaft which is rotatably connected to a second end portion of the control link through an arm link; a housing rotatably supporting therewithin the control shaft; a wave gear speed reduction device arranged to reduce a rotation speed of the drive motor, and to transmit the reduced rotation speed to the control shaft; a first bearing portion provided between the control shaft and a first axial end portion of the wave generation device of the wave gear speed reduction device; and a second bearing portion provided between the housing and a second axial end portion of the wave generation device, a part of at least one of the first bearing portion and the second bearing portion being disposed within an axial width of an outer circumference portion of the wave generation device.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic view schematically showing an embodiment according to the present invention.

FIG. **2** is a perspective view showing an actuator of a variable compression ratio mechanism according to the present invention.

FIG. **3** is an exploded perspective view showing the actuator in the first embodiment.

FIG. **4** is a plan view showing the actuator.

FIG. **5** is a left side view of the actuator.

FIG. **6** is a sectional view taken along a section line A-A of FIG. **4**.

FIG. **7** is a sectional view showing a main part in the first embodiment.

FIG. **8** is a sectional view showing a state in which a control shaft is assembled to a control shaft in the first embodiment.

DETAILED DESCRIPTION OF THE INVENTION

Hereinafter, an actuator of a variable compression ratio mechanism according to one embodiment of the present invention is illustrated with reference to the drawings. In this embodiment, there are provided a variable compression ratio mechanism (VCR) arranged to vary a mechanical compression ratio of an in-line four cylinder gasoline internal combustion engine, and an actuator thereof.

First Embodiment

FIG. **1** schematically shows a variable compression ratio mechanism according to the present invention. This is identical to a structure of FIG. **1** of the conventional art of Japanese Patent Application Publication No. 2011-169152. Accordingly, this is briefly illustrated.

There are provided an upper link **3** including an upper end which is rotatably connected to a piston pin **2** of a piston **1** that reciprocates within a cylinder of a cylinder block of an internal combustion engine; and a lower link **5** which is rotatably connected to a crank pin **4***a* of a crank shaft **4**. Lower link **5** is rotatably connected with a lower end of upper link **3** through a connection pin **6**. Lower link **5** is rotatably connected to an upper end portion of a first control link **7** through a connection pin **8**.

First control link **7** includes a lower end portion connected with a connection mechanism **9** constituted by a plurality of link members. This connection mechanism **9** includes a first control shaft **10**; a second control shaft **11** which is a control shaft; and a second control link **12** which is a control link connecting first control shaft **10** and second control shaft **11**.

First control shaft **10** extends within the engine in parallel with crank shaft **4** in a cylinder row direction. First control shaft **10** includes a first journal portion **10***a* rotatably supported by a main body of the engine; a plurality of control eccentric shaft portion **10***b* each of which a lower end portion of first control link **7** of the each cylinder is rotatably mounted to; and an eccentric shaft portion **10***c* to which a first end portion **12***a* of second control link **12** is rotatably mounted.

Each of control eccentric shaft portions **10***b* is provided through first arm portion **10***d* at a position which is eccentric (depart) from first journal portion **10***a* by a predetermined amount. Similarly, eccentric shaft portion **10C** is provided through second arm portion **10***e* at a position which is eccentric from first journal portion **10***a* by a predetermined amount.

Second control shaft **11** is rotatably supported within a housing **20** (described later) through a plurality of journal portions. An arm link **13** is connected and fixed to the second control shaft **11**. Arm link **13** is rotatably connected with second end portion **12***b* of second control link **12**.

As shown in FIGS. **2** and **3**, second control link **12** has a lever shape. Second control link **12** includes first end portion **12***a* which has a substantially straight shape, and to which eccentric shaft portion **10***c* is connected; and a second end portion **12***b* which has a substantially arc (curved) shape by bending, and to which arm link **13** is connected. First end portion **12***a* of second control link **12** includes an insertion hole **12***c* which is formed at a tip end portion of first end portion **12***a*, which penetrates through first end portion **12***a*, and through which eccentric shaft portion **10***c* is rotatably inserted. On the other hand, second end portion **12***b* of second control link **12** includes tip end portions **12***d* and **12***d* which are formed into a bifurcated shape (two-forked shape). A protrusion portion **13***b* (described later) of arm link **13** is sandwiched and held between tip end portions **12***d* and **12***d* of second end portion **12***b*. Moreover, second end portion **12***b* includes fixing holes **12***e* and **12***e* which penetrate through second end portion **12***b*, and which a connection pin **14** connected with protrusion portion **13***a* is fit and fixed in.

Arm link **13** is formed independently of second control shaft **11**. Arm link **13** is formed from an iron series metal into an annular shape having a large thickness. Arm link **13** includes a press-fit hole **13***a* which is formed in a substantially central portion of arm link **13**, and which is fit and fixed on a fixing portion formed between the front and rear journal portions of second control shaft **11**; and a protrusion portion **13***b* which has a U-shape, which is formed on an outer circumference of arm link **13**, and which protrudes in the radial direction. Press-fit hole **13***a* and protrusion portion **13***b* are integrally formed to constitute arm link **13**. This protrusion portion **13***b* includes a connection hole **13***c* in which connection pin **14** is rotatably supported. A shaft center (connection pin **14**) of this connection hole **13***c* is eccentric from the shaft center of second control shaft **11** in the radial direction through protrusion portion **13***b*.

Second control shaft **11** is arranged to vary a rotational position by a torque (rotational force) transmitted from a drive motor **22** through a speed reduction device **21** which is a part of the actuator, thereby to rotate control shaft **10** through second control link **12**, and to move a position of the lower end portion of first control link **7**. With this, a posture of lower link **5** is varied so that the stroke characteristic of piston **1** is varied. Consequently, the engine compression ratio is varied in accordance with the variation of the stroke characteristic of piston **1**.

As shown in FIG. **2** to FIG. **7**, the actuator includes second control shaft **11**; a housing **20** rotatably supporting second control shaft **11** within housing **20**; speed reduction device **21** provided within a rear end side portion of housing **20**; and drive motor **22** provided on a rear end side of speed reduction device **21**.

Second control shaft **11** includes a shaft main body **23** which is integrally made from an iron series metal; and a fixing flange **24** provided integrally with a rear end portion of shaft main body **23**. Shaft main body **23** is formed into a stepped shape in an axial direction. Shaft main body **23** includes a first journal portion **23***a* which is on a tip end side, and which has a small diameter; a fixing portion **23***b* which has a middle diameter, which is located at an intermediate portion, and to which arm link **13** is fit from first journal portion **23***a*'s side through press-fit hole **13***a*; and a second journal portion **23***c* which has a large diameter, and which is on the fixing flange **24**'s side. Moreover, shaft main body **23** includes a first stepped portion **23***d* located between fixing portion **23***b* and second journal portion **23***c*; and a second stepped portion **23***e* located between first journal portion **23***a* and fixing portion **23***b*.

First stepped portion **23***d* includes one end side hole edge which is on the second journal portion **23***c*'s side. When press-fit hole **13***a* of arm link **13** is fit on fixing portion **23***b* from the first journal portion **23***a*'s side, this one end side hole edge of first stepped portion **23***d* is abutted in the axial direction. With this, first stepped portion **23***d* restricts the movement of arm link **13** in a direction toward the second journal portion **23***c*. On the other hand, when shaft main body **23** is inserted within support hole **30**, second stepped portion **23***e* is abutted on a stepped hole edge **30***c* (described later) of support hole **30** so as to restrict a movement in the axial direction.

Fixing flange **24** includes six bolt insertion holes **24***a* which are formed in an outer circumference portion of fixing flange **24** at a regular interval in the circumferential direction, and which penetrate through fixing flange **24**. Fixing flange **24** is connected through a thrust plate **26** to a circular spline **27** which is an internal gear of speed reduction device **21**, by the six bolts **25** inserted though the bolt insertion holes **24***a*.

Moreover, this fixing flange **24** includes a first bearing support portion **24***b* which is a circular shape, and which is formed in an inner circumference portion of fixing flange **24** on a first receiving chamber **28***a*'s side of a housing main body **28** (described later), and which protrudes. This first bearing support portion **24***b* includes a first support groove **24***c* formed on the inner circumference side of the first bearing support portion **24***b*.

Housing **20** includes housing main body **28** which is formed from an aluminum alloy into a substantially cube; and a cover **29** which closes, through an O-ring **51**, one end opening of a first receiving chamber **28***a* which is a large diameter circular groove shape, and which is provided on the inner side of the rear end side of housing main body **28**.

Housing main body **28** includes a second receiving chamber **28***b* which is formed within a front portion of first receiving chamber **28***a* (on a left side of FIG. **6**), and which extends in a lateral direction, and a support hole **30** which is formed within housing main body **28** from a bottom surface of first receiving chamber **28***a* in the axial direction, through which the shaft main body **23** of control shaft **13** is inserted and disposed, and which penetrates through second receiving chamber **28***b* in a direction perpendicular to second receiving chamber **28***b*.

A holding hole **31** is elongated from support hole **30** in the axial direction. An angle sensor **32** is received and disposed within this holding hole **31**. Angle sensor **32** is arranged to sense a rotational angle position of control shaft **13**.

Cover **29** is made from an aluminum alloy similarly to housing main body **28**. Cover **29** includes a motor shaft insertion hole **29***a* formed at a substantially central portion, and which penetrates through cover **29**; four boss portions **29***b* which are formed on an outer circumference surface, and which protrude in the radial direction; and bolt insertion holes which are formed in the four boss portions **29***b*. Four bolts **43** are inserted from the drive motor **22**'s side into the bolt insertion holes. With this, cover **29** is fixed to housing main body **28**.

Furthermore, this cover **29** includes a second bearing support portion **29***c* which has an annular shape, and which is formed on an inner circumference portion of an inner end surface on the first receiving chamber **28***a*'s side, and which protrudes. Cover **29** includes six internal screw holes **29***d* which are formed on an outer circumference portion of an inner end surface, and which extend in the axial direction, and in which bolts **41** for connecting a second circular spline **38** (described later) are screwed. Moreover, cover **29** includes internal screw holes **29***e* which is formed in a rear end of cover **29**, and into which bolts **49** for connecting a motor housing **45** (described later) are screwed.

Second bearing support portion **29***c* protrudes in a direction toward first receiving chamber **28***a*. Second bearing support portion **29***c* includes a second support groove **29***f* which has a circular shape, and which is formed on an inner circumference side of the second bearing support portion **29***c*.

As shown in FIG. **6** and FIG. **7**, second receiving chamber **28***b* receives a connection portion between arm link **13** and second end portion **12***b* of control link **12** by connection pin **14**. Second receiving chamber **28***b* has an overall space by which it is possible to ensure free swing movements of control link **12** and arm link **13**. Moreover, second receiving chamber **28***b* has a width which is slightly greater than a width of second end portion **12***b* of control link **12** so as to suppress back-lash (rattle) of the operation.

As shown in FIG. **6**, support hole **30** is formed into a stepped shape so that an outside diameter of an inner circumference surface of support hole **30** corresponds to an outside diameter of shaft main body **23** of second control shaft **11**. Support hole **30** includes a first bearing hole **30***a* which has a small diameter, and on which first journal portion **23***a* is supported; a portion which is positioned at a position corresponding to the position of fixing portion **23***b*, that is, which is opened to second receiving chamber **28***b*; and a second bearing hole **30***b* which has a large diameter, and on which second journal portion **23***c* is supported.

First bearing hole **30***a* includes a stepped hole edge **30***c* confronting second receiving chamber **28***b*. This stepped hole edge **30***c* of first bearing hole **30***a* is arranged to be abutted on the second stepped portion **23***e* in the axial direction when second bearing main body **23** is inserted into support hole **30**, and thereby to restrict further insertion of second shaft main body **23**. Besides, the inner circumference portion of fixing flange **24** is abutted on the outside hole edge of second bearing hole **30***b*, so as to restrict a maximum movement position of shaft main body **23** with respect to support hole **30**.

As shown in FIG. **2** and FIG. **3**, angle sensor **32** includes a sensor cover **32***a* which has a cap shape, and which is fixed on the inner circumference surface of the holding hole **31** by the press-fit; a rotor **32***b* which is for sensing the angle, which is disposed on the inner circumference side of the sensor cover **32***a*; a sensor portion **32***c* which is provided at a substantially central portion of sensor cover **32***a*, and which is arranged to sense a rotational position of rotor **32***b*. The sensor portion **32***c* is arranged to output the sensed signal to a control unit (not shown) configured to sense an operating state of the engine. The rotor **32***b* includes a tip end protruding portion **32***d* fixed to a fixing hole formed at a tip end side of shaft main body **23** by the press-fit.

In sensor cover **32***a*, a portion between sensor cover **32***a* and holding hole **31** is sealed by a gasket **33**. Sensor cover **32***a* is mounted to housing **20** with sensor portion **32***c* by two bolts **34**. Moreover, sensor cover **32***a* includes three O-rings **35** which are provided on the outer circumference of a cylindrical portion. With this, the insertion of the oil in a direction toward the sensor portion **32***c* is restricted.

Speed reduction device **21** is a wave gear type. Various components of speed reduction device **21** is received within first receiving chamber **28***a* of housing main body **28** which is closed by cover **29**. That is, speed reduction device **21** includes a first circular spline **27** which has an annular shape, which is fixed to fixing flange **24** by bolts, and which includes an inner circumference on which a plurality of internal teeth **27***a* are formed; a flex spline **36** which is disposed inside first circular spline **27**, and which is an external gear including a plurality of external teeth **36***a* that are formed on an outer circumference surface, and that are engaged with internal teeth **27***a*; a wave generator **37** which is a wave generating device, which includes an oval outer circumference surface that is slid on a part of an inner circumference surface of flex spline **36**; and a second circular spline **38** which is disposed at an axial one end side of first circular spline **27**, and which includes internal teeth **38***a* that are formed on the inner circumference surface, and that the external teeth **36***a* of flex spline **36** are engaged.

First circular spline **27** includes six internal screw holes **27***b* which are formed at a regular interval in the circumferential direction, and into which bolts **25** are screwed.

Flex spline **36** is formed from metal material into a thin cylindrical shape by which the flex spline **36** can flexibly vary shape thereof. External teeth **36***a* of flex spline **36** has a number of teeth which is smaller than the number of teeth of internal teeth **27***a* of first circular spline **27** by one.

As shown in FIG. **6**, wave generator **37** includes a through hole **37***a* which has a relatively large diameter, which has a substantially circular shape, and which is formed at a substantially central portion of wave generator **37**; and a plurality of internal teeth **37***b* formed on the inner circumference surface of through hole **37***a*. The oval outer circumference surface of this wave generator **37** is formed into a plane shape. This oval outer circumference surface of wave generator **37** is abutted on the plane inner circumference surface of flex spline **36**.

This wave generator **37** includes an outer circumference portion **37***c* having an axial width W which is relatively small. Moreover, this wave generator **37** includes an inner circumference portion **37***d*; and recessed portions **37***e* and **37***f* formed on both axial end surfaces of inner circumference portion **37***d*. With this, the entire of the wave generator **37** has a constriction shape. That is, axial width W1 of inner circumference portion **37***d* is sufficiently smaller than an axial width W of outer circumference portion **37***c* by the both recessed portions **37***e* and **37***f*. With this, the entire of the wave generator **37** is formed into the constriction shape.

Moreover, wave generator **37** includes cylindrical protruding portions **37***g* and **37***h* integrally formed, respectively, on the inside of the inner circumference portion **37***d*, that is, the front and rear hole edges of through hole **37***a* in the axial direction. Front and rear first and second ball bearings **39** and **40** (first and second bearing portions) are disposed, respectively, between the protrusion portions **37***g* and **37***h*, and the first support groove **24***c* of fixing flange **24** and second support groove **29***f* of cover **29**. The entire of wave generator **37** is rotatably supported by these first and second ball bearings **39** and **40**.

In particular, first ball bearing **39** includes an inner wheel which is fixed on the outer circumference surface of the one protrusion portion **37***g* by the press-fit, and an outer wheel which is fixed on the inner circumference surface of the first support groove **24***c* by the press-fit. On the other hand, second ball bearing **40** includes an inner wheel which is fixed on the outer circumference surface of the other protrusion portion **37***h* by the press-fit; and an outer wheel which is fixed on the inner circumference surface of the second support groove **29***f*. Accordingly, first and second ball bearings **39** and **40** include, respectively, inner portions which confront each other in the axial direction, and which are positioned within the axial width W of outer circumference portion **37***c*. Accordingly, first and second ball bearings **39** and **40** are overlapped with outer circumference portion **37***c* in the radial direction.

Second circular spline **38** includes a flange portion **38***b* which is provided on the outer circumference side; and six bolt insertion holes which are formed in flange portion **38***b*, and which penetrate through flange portion **38***b*. Second circular spline **38** is fixed to the inner end portion of cover **29** through second thrust plate **42** by six bolts **41** inserted through these bolt insertion holes. Furthermore, internal teeth **38***a* of this second circular spline **38** has the number of teeth which is identical to the number of teeth of the external teeth **36***a* of flex spline **36**. Accordingly, the internal teeth **38***a* of this second circular spline **38** has the number of the teeth smaller than the number of the teeth of the internal teeth **27***a* of first circular spline **27** by one. By this difference of the numbers of the teeth, the speed reduction ratio is determined.

Drive motor **22** is a brushless electric motor. As shown in FIG. **3** and FIG. **6**, drive motor **22** includes a motor casing **45** which has a bottomed cylindrical shape; a coil **46** which has a cylindrical shape, and which is fixed on the inner circumference surface of motor casing **45**; a magnetic rotor **47** which is rotatably provided within coil **46**; and a motor shaft **48** which includes one end portion **48***a* which is fixed at a substantially axial center of magnetic rotor **47**.

Motor casing **45** includes four boss portions **45***a* which are formed on an outer circumference of an front end; and bolt insertion holes **45***b* which are formed in four boss portions **45***a*, and through which four bolts **49** are inserted. Motor casing **45** is mounted on a rear end portion of cover **29** through an O-ring **50** by four bolts **49**. Furthermore, a connector portion **67** is integrally provided on an outer circumference of motor casing **45**. Connector portion **67** is arranged to receive a control current from the control unit.

Magnetic rotor **47** includes positive magnetic poles and negative magnetic poles which are alternately disposed on the outer circumference in the circumferential direction. Moreover, magnetic rotor **47** includes a fixing hole **47***a* which is formed at a substantially central portion, and to which one end portion **48***a* of motor shaft **48** is fixed by the press-fit, and which penetrates through magnetic rotor **47**.

Motor shaft **48** includes first end portion **48***a* which protrudes from one end surface of magnetic rotor **47**, and which has a tip end portion supported by a ball bearing **52** including an outer wheel fixed within an end wall of motor casing **45**. Moreover, motor shaft **48** includes a second end portion **48***b* which is supported by a ball bearing **53** including an outer wheel fixed on the inner circumference of motor shaft insertion hole **29***a* of cover **29**. Furthermore, external teeth **48***c* are formed on the outer circumference surface of motor shaft **48** which is other than second end portion **48***b*. External teeth **48***c* are engaged with internal teeth **37***b* of wave generator **37**.

Ball bearing **53** is held within a holding groove of cover **29** by screws **56** through a substantially disc shaped retainer **54**.

A resolver **55** is disposed at a substantially central position of motor shaft **48** in the axial direction. Resolver **55** is arranged to sense a rotation angle of motor shaft **48**. This resolver **55** includes a resolver rotor **55***a* fixed on the outer circumference of motor shaft **48** by the press-fit; and a sensor portion **55***b* arranged to sense a compound leaf shaped target formed on the outer circumference surface of resolver rotor **55***a*. This sensor portion **55***b* is fixed within the cover **28** by two screws **56**. Moreover, the sensor portion **55***b* is arranged to output the sensed signal to the control unit.

Second control shaft **11** includes an introduction portion which is formed inside second control shaft **11** in the axial direction, and which is arranged to introduce the lubrication oil pressurized and transmitted from an oil pump (not shown); and a plurality of radial holes **65***a* and **65***b* which are formed inside second control shaft **11** in the radial direction, and which are connected with the introduction portion. The introduction portion includes an oil chamber **64***a* which has a substantially conical shape, which is formed at a substantially central portion of fixing flange **24**, and to which a lubrication oil is supplied from an oil hole (not shown); and an axial hole **64***b* which is formed from oil chamber **64***a* along a direction of the center of the shaft of the inside of second control shaft **11**.

The one radial hole **65***a* includes an inner end opened in the tip end portion of the axial hole **64***b*; and an outer end opened in a clearance between the outer circumference surface of first journal portion **23***a* and first bearing hole **30***a*. The one radial hole **65***a* is arranged to supply the lubrication oil to this clearance. As shown in FIG. **7**, the other radial hole **65***b* is connected to an oil hole **65***c* formed inside the arm link **13**. The other radial hole **65***b* is arranged to supply the lubrication oil through this oil hole **65***c* to a portion between the inner circumference surface of connection hole **13***c* and the outer circumference surface of the connection pin **14**.

[Functions and Effects of First Embodiment]

By this embodiment, when arm link **13** is fixed within receiving chamber **28***b* to shaft main body **23** of second control shaft **11** by the press-fit, first in a state where second end portion **12***b* of control link **12** and protrusion portion **13***b* of arm link **13** are connected with each other by connection pin **14**, this connection portion is received, positioned, and fixed within receiving chamber **28***b* by two jigs **62** and **63**, as shown in FIG. **8**. In this state, shaft main body **23** is inserted into press-fit hole **13***a* from the tip end portion's side (the first journal portion **23***a*'s side). This connection portion (arm link **13**) is press-fit on the outer circumference surface of fixing portion **23***b* in the axial direction. This connection portion (arm link **13**) is press-fit until first stepped portion **23***d* is abutted on the one end side hole edge.

Then, jigs **62** and **63** are detached. With this, the assembling operation of arm link **13** with respect to second control shaft **11** is finished.

In this way, in this embodiment, second control shaft **11** and arm link **13** are divided into each other. Arm link **13** is connected to shaft main body **23** within receiving chamber **28***b*. Unlike the conventional art in which shaft main body **23** and arm link **13** are integrally formed, it is unnecessary that the inside diameter of motor shaft insertion hole **30** of housing main body **28** is formed into a large size for inserting arm link **13**. Moreover, it is utterly unnecessary that housing main body **28** is divided into the upper section and the lower section.

Accordingly, it is possible to suppress the increase of the entire size of the housing **20**, and to attain the size reduction and the weight reduction of housing **20**. Accordingly, it is possible to improve mountability of the variable compression ratio mechanism to the engine.

Furthermore, second control shaft **11** and arm link **13** are different members. With this, it is possible to improve the freedom of the length of arm link **13**, and to increase the length of arm link **13** in accordance with the size of receiving chamber **28***b*. Accordingly, it is possible to reduce the reverse input load from control link **12** toward second control shaft **11**'s side. With this, it is possible to reduce the load of speed reduction device **21** and drive motor **22**.

Moreover, in this embodiment, the entire axial width of wave generator **37** is small. In particular, wave generator **37** is formed into a contraction shape by the recessed portions **37***e* and **37***f* formed on the both end surfaces of inner circumference portion **37***d*. Accordingly, the axial width W1 becomes small. Consequently, it is possible to close the positions of first and second ball bearings **39** and **40**. Therefore, it is possible to close cover **29** and fixing flange **27** which support, respectively, first and second ball bearings **39** and **40**. Accordingly, it is possible to sufficiently decrease the axial length of the entire of housing **20**. Consequently, it is possible to decrease the axial size of the entire of housing, in cooperation with the size reduction of housing main body **28**.

Furthermore, it is possible to slightly move the position of fixing flange **27** toward the cover **29**'s side. Accordingly, it is possible to further increase the axial length of second bearing hole **30***b*. With this, it is possible to increase bearing area of second journal portion **23***c* by second bearing hole **30***b*. Accordingly, it is possible to receive the larger load by second bearing hole **30***b*.

That is, large alternating torque generated in piston **1** is transmitted to control link **12**. This alternating torque is transmitted from arm link **13** to shaft main body **23** of second control shaft **11**. The large load is transmitted from first and second journal portions **23***a* and **23***c* to the inner circumference surfaces of first and second bearing holes **30***a* and **30***b*, so that the surface pressures between the inner circumference surfaces of first and second bearing holes **30***a* and **30***b* becomes large. The abrasion is generated on the inner circumference surfaces of first and second bearing holes **30***a* and **30***c* of the aluminum alloy by this surface pressures and high speed sliding friction. With this, a relatively large clearance may be generated between first and second journal portions **23***a* and **23***c* and first and second bearing holes **30***a* and **30***b*.

In a case where this clearance becomes large, in second control shaft **11**, the first journal portion **23***a*'s side which is a tip end portion of shaft main body **23** becomes easy to be pivoted about second ball bearing **40**. With this, flex spline **36** receives the alternating load through first ball bearing **39**, and wave generator **37**. Conventionally, the inner circumferential portion of wave generator **37** has a long axial length. Accordingly, the swing amount around second ball bearing **40** becomes large. The large eccentric load is acted to flex spline **36**. The flexible shape variation (deformation) becomes easy to be partially generated. Moreover, the deterioration of the durability of those may be generated by the increase of the local surface pressure and the poor lubrication due to partial contact (misaligned abutment) of track surface of first ball bearing **39**.

Accordingly, in this embodiment, the position of first ball bearing **39** is closer to the drive motor **22**'s side. With this, fixing flange **24** can be moved in the same direction. Consequently, it is possible to increase the axial length of second bearing hole **30***d*. Therefore, it is possible to decrease an overhang amount from second ball bearing **40** which is a fulcrum to flex spline **36** and first ball bearing **39** which are points of action, and thereby to suppress the swing amount of shaft main body **23** to a small amount. Accordingly, it is possible to decrease the partially flexible amount of flex spline **36**, and to suppress the generation of the partial contact of second ball bearing **40**. With this, it is possible to suppress the decrease of the durability of those.

Furthermore, shaft main body **23** is supported through the front and rear first and second journal portions **23***a* and **23***c* in front and rear first and second bearing holes **30***a* and **30***b* of support hole **30**. Accordingly, it is possible to stably constantly support second control shaft **11**, and thereby to further suppress the vibration and noise by the alternating load.

Moreover, in this embodiment, shaft main body **23** has a stepped shape from second journal portion **23***c* having the maximum diameter through the fixing portion **23***b* having the middle diameter to the first journal portion **23***a* having the minimum diameter. Accordingly, it is possible to improve the insertion characteristics to support hole **30**.

Furthermore, arm link **13** is fixed through press-fit hole **13***a* on fixing portion **23***b* of shaft main body **23** in the axial direction. Accordingly, it is possible to ease the connection operation of arm link **13** and shaft main body **23**.

Moreover, second stepped portion **23***e* of shaft main body **23** is abutted on stepped hole edge **30***c* of support hole **30**. With this, it is possible to ease the positioning in the axial direction at the insertion of shaft main body **23**. Furthermore, it is possible to restrict the axial position of arm link **13** at the press-fit by using first stepped portion **23***d* of shaft main body **23**. Accordingly, it is possible to ease the positioning at this point.

Moreover, shaft main body **23** of second control shaft **11** is made from iron series metal. On the other hand, the entire of housing **20** including first and second bearing holes **30***a* and **30***b* are formed from aluminum alloy. With this, difference between the iron and the aluminum alloy by thermal expansion and contraction becomes small since the first bearing hole **30***a* has a small diameter shape. With this, it is possible to suppress the generation of the twist due to the backlash between first journal portion **23***a* and first bearing hole **30***a*.

The present invention is not limited to the structure according to the embodiment. For example, it is optional to employ a spline connection and a bolt connection, as a fixing means of arm link **13** with respect to shaft main body **23**, in addition to the press-fit.

Moreover, the present invention is applicable to actuators of other link mechanisms for internal combustion engine, in addition to the variable compression ratio mechanism.

[a] In the actuator of the variable compression ratio mechanism, the second bearing portion includes an outer wheel which is fixed on the housing, and an inner wheel which is fixed on a first axial end portion of an inner circumference portion of the wave generation device; and the first axial end portion of the wave generation device is rotatably supported by the housing.

[b] In the actuator of the variable compression ratio mechanism, the first bearing portion includes an outer wheel fixed on an inner circumference portion of the control shaft, and an inner wheel fixed at a second axial end portion of the inner circumference portion of the wave generation device; and the second axial end portion of the wave generation device is rotatably supported by the control shaft.

[c] In the actuator of the variable compression ratio mechanism, the control shaft is rotatably supported within the housing by a front bearing hole and a rear bearing hole which are formed within the housing at front and rear positions in an axial direction to sandwich the arm link.

[d] In the actuator of the variable compression ratio mechanism, the control link is rotatably connected to an eccentric portion of the arm link fixed to the control shaft.

[e] In the actuator of the variable compression ratio mechanism, the actuator further includes an angle sensor provided to a tip end portion of the control shaft, and arranged to sense an rotation angle of the control shaft.

[f] In the actuator of the variable compression ratio mechanism, the variable compression ratio mechanism includes a first control shaft which is different from the control shaft, and which is arranged to be rotated to vary a position of a piston; the control link is connected to the first control shaft to be eccentric from the first control shaft; and the control link is arranged to vary a posture of the control link to vary a rotation angle of the first control shaft.

[g] In the actuator of the variable compression ratio mechanism, the housing includes a speed reduction device receiving portion which is formed within the housing, and which receives the wave gear speed reduction device; and the housing includes a bearing hole which is on the rear end side of the housing, and which extends toward the speed reduction device receiving portion.

By this invention, the axial bearing hole of the control shaft extends toward the wave generating device. Accordingly, it is possible to increase the axial length of the bearing hole. Consequently, it is possible to receive the larger load by this bearing hole.

In this embodiment according to the present invention, the bearing hole of the control shaft extends in a direction toward the wave generation device of the speed reduction device. Accordingly, it is possible to increase the axial length of the bearing hole, and thereby to receive the larger load.

[h] In the actuator of the variable compression ratio mechanism, the control shaft includes a first journal portion and a second journal portion which are supported by two bearing holes of the housing. The first journal portion is located at a tip end portion. The second journal portion is located at a base end portion. The second journal portion has an outside diameter larger than an outside diameter of the first journal portion.

In this invention, the outside diameter of the first journal portion is larger than the outside diameter of the second journal portion. Accordingly, it is possible to receive the larger load.

[i] In the actuator of the variable compression ratio mechanism, the control link is rotatably connected to an eccentric portion of the arm link which is fixed to the control shaft by the press-fit.

[j] In the actuator of the variable compression ratio mechanism, the control shaft includes a fixing flange located at a base end portion on the speed reduction device's side; and the fixing flange includes an outer circumference side fixed on an outer circumference of the circular spline.

[k] In the actuator of the variable compression ratio mechanism, the fixing flange includes a first support groove which is formed on an inner circumference side of the fixing flange, and which supports the outer circumference of the first bearing portion.

[l] In the actuator of the variable compression ratio mechanism, the wave generation device includes a bearing portion which is formed on the inner circumference side of the wave generation device, and which extends toward the control shaft's side; and the bearing portion includes an outer circumference on which the inner wheel of the second bearing portion is fixed.

[m] In the actuator of the variable compression ratio mechanism, the second bearing portion includes an end portion which is on the wave generation device's side, and which is disposed to be overlapped with a sliding range between the wave generation device and the external teeth.

[n] In the actuator of the variable compression ratio mechanism, the control shaft includes an oil passage which is formed within the control shaft, and which extends in the axial direction.

[o] In the actuator of the variable compression ratio mechanism, the arm link includes an oil hole which is formed in the arm link, and which connects the oil passage and the connection portion between the control link and the arm link.

[p] In the actuator of the variable compression ratio mechanism, the flange portion includes a recessed portion forming portion which forms the recessed portion, which protrudes

toward the wave generation device with respect to the outer circumference of the flange portion; and the wave forming portion is disposed so that a part of the recessed portion forming section is overlapped with the inside of the first internal gear in the axial direction.

The entire contents of Japanese Patent Application No. 2014-018991 filed Feb. 4, 2014 are incorporated herein by reference.

Although the invention has been described above by reference to certain embodiments of the invention, the invention is not limited to the embodiments described above. Modifications and variations of the embodiments described above will occur to those skilled in the art in light of the above teachings. The scope of the invention is defined with reference to the following claims.

What is claimed is:

1. An actuator of a variable compression ratio mechanism which is arranged to vary at least one of a top dead center position and a bottom dead center position of a piston of an internal combustion engine, and thereby to vary a mechanical compression ratio, the actuator comprising:

a control link including a first end portion connected to the variable compression ratio mechanism, and a second end portion, and arranged to vary a position characteristic of the piston;

a control shaft which is connected in an eccentric state through an arm link to a second end portion of the control link;

a housing which includes a support hole formed within the housing, and which rotatably supports the control shaft;

a wave gear speed reduction device which is arranged to reduce a rotation speed of a drive motor, and to transmit the reduced rotation speed to the control shaft;

a first bearing portion which is provided between the control shaft and a wave generation device of the wave gear speed reduction device, and which rotatably supports a first axial end portion of the wave generation device; and

a second bearing portion which is provided between the housing and the wave generation device, and which rotatably supports a second axial end portion of the wave generation device,

at least one of the first bearing portion and the second bearing portion being disposed inside an axial width of an outer circumference portion of the wave generation device.

2. The actuator for the variable compression ratio mechanism as claimed in claim **1**, wherein the control shaft is rotatably supported within the housing by a front bearing hole and a rear bearing hole which are formed within the housing at front and rear positions in an axial direction to sandwich the arm link.

3. The actuator for the variable compression ratio mechanism as claimed in claim **2**, wherein the housing includes a speed reduction device receiving portion which is formed within the housing, and which receives the wave gear speed reduction device; and the rear bearing hole which is on the rear end side of the housing extends toward the speed reduction device receiving portion.

4. The actuator for the variable compression ratio mechanism as claimed in claim **1**, wherein the housing includes a speed reduction device receiving portion which is formed within the housing, and which receives the wave gear speed reduction device; and the rear bearing hole which is on the rear end side of the housing extends toward the speed reduction device receiving portion.

5. The actuator for the variable compression ratio mechanism as claimed in claim **4**, wherein the second bearing portion includes an outer wheel which is fixed on the housing, and an inner wheel which is fixed on a first axial end portion of an inner circumference portion of the wave generation device; and the first axial end portion of the wave generation device is rotatably supported by the housing.

6. The actuator for the variable compression ratio mechanism as claimed in claim **5**, wherein the first bearing portion includes an outer wheel fixed on an inner circumference portion of the control shaft, and an inner wheel fixed at a second axial end portion of the inner circumference portion of the wave generation device; and the second axial end portion of the wave generation device is rotatably supported by the control shaft.

7. The actuator for the variable compression ratio mechanism as claimed in claim **5**, wherein the control shaft includes a fixing flange located at a base end portion on the speed reduction device's side; and the fixing flange includes an outer circumference side fixed on an outer circumference of a circular spline.

8. The actuator for the variable compression ratio mechanism as claimed in claim **7**, wherein the fixing flange includes a first support groove which is formed on an inner circumference side of the fixing flange, and which supports the outer circumference of the first bearing portion.

9. The actuator for the variable compression ratio mechanism as claimed in claim **1**, wherein the wave gear speed reduction device includes

a first inner gear which has an internal teeth formed on an inner circumference surface, and which is arranged to rotate as a unit with the control shaft,

a second inner gear which is fixed to the housing, and which has an internal teeth which is formed on an inner circumference surface, and whose a number of the teeth is smaller than a number of the teeth by one, and

an external gear that extends within the first inner gear and the second inner gear, that is disposed coaxially with the first inner gear and the second inner gear, and that has external teeth which is formed on an outer circumference surface of the external gear, and whose a number of the teeth is identical to the number of the teeth of the second internal gear;

the wave generation device includes an outer circumference surface which is disposed on an inner circumference surface of the external teeth to be slid on the inner circumference surface of the external gear; and the wave generation device is arranged to engage the external teeth of the outer gear with the internal teeth of the first inner gear and the internal teeth of the second inner gear by the rotation of the motor.

10. The actuator for the variable compression ratio mechanism as claimed in claim **1**, wherein the control link is rotatably connected to an eccentric portion of the arm link fixed to the control shaft.

11. The actuator for the variable compression ratio mechanism as claimed in claim **1**, wherein the actuator further comprises an angle sensor provided to a tip end portion of the control shaft, and arranged to sense an rotation angle of the control shaft.

12. The actuator for the variable compression ratio mechanism as claimed in claim **1**, wherein the variable compression ratio mechanism includes a first control shaft which is different from the control shaft, and which is arranged to be rotated to vary a position of a piston; the control link is connected to the first control shaft to be eccentric from the first control shaft; and the control link is arranged to vary a posture of the control link to vary a rotation angle of the first control shaft.

13. An actuator of a variable compression ratio mechanism which is arranged to vary at least one of a top dead center position and a bottom dead center position of a piston of an internal combustion engine, and thereby to vary a mechanical compression ratio, the actuator comprising:

a control shaft arranged to be drivingly rotated by a drive motor;

a control link which includes a first end portion connected to the variable compression ratio mechanism, and a second end portion linked with the control shaft, and which is arranged to vary a position characteristic by a rotation of the control shaft;

a housing which includes a support hole formed within the housing, and which rotatably supports the control shaft;

a wave gear speed reduction device which Is arranged to reduce a rotation speed of a drive motor, and to transmit the reduced rotation to the control shaft;

a first bearing portion including an outer wheel which is fixed on an inner circumference portion of the control shaft, and an inner wheel which is fixed to a first axial end portion of an inner circumference portion of a wave generation device; and

a second bearing portion including an outer wheel fixed to the housing, and an inner wheel fixed to a second axial end portion of the inner circumference portion of the wave generation device,

at least one of the first axial end portion and the second axial end portion of the inner circumference portion of the wave generation device including a recessed portion, and

a part of at least one of the first bearing portion and the second bearing portion being received within the recessed portion.

14. The actuator for the variable compression ratio mechanism as claimed in claim **13**, wherein the housing

includes a speed reduction device receiving portion which is formed within the housing, and which receives the wave gear speed reduction device; and the housing includes a bearing hole which is on the rear end side of the housing, and which extends toward the speed reduction device receiving portion.

15. An actuator used for driving a link mechanism of an internal combustion engine, the actuator comprising:

a control link including a first end portion connected to the link mechanism;

a control shaft which is rotatably connected to a second end portion of the control link through an arm link;

a housing rotatably supporting therewithin the control shaft;

a wave gear speed reduction device arranged to reduce a rotation speed of the drive motor, and to transmit the reduced rotation speed to the control shaft;

a first bearing portion provided between the control shaft and a first axial end portion of the wave generation device of the wave gear speed reduction device; and

a second bearing portion provided between the housing and a second axial end portion of a wave generation device,

a part of at least one of the first bearing portion and the second bearing portion being disposed within an axial width of an outer circumference portion of the wave generation device.

16. The actuator for the variable compression ratio mechanism as claimed in claim **15**, wherein the housing includes a speed reduction device receiving portion which is formed within the housing, and which receives the wave gear speed reduction device; and the housing includes a bearing hole which is on a rear end side of the housing, and which extends toward the speed reduction device receiving portion's side.

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